SYSTEM FOR DETECTING GAS IN A WELLBORE DURING DRILLING

The present invention relates to a system for detecting the presence of formation gas in a stream of drilling fluid flowing through a wellbore during drilling of the wellbore. In the search for hydrocarbon fluids present in earth formation layers it is important to detect the inflow of gas from the earth formation into the wellbore during drilling, at an early stage. If the gas is at high pressure early detection is crucial to ensure proper well control and to forego inadvertent wellbore conditions. Furthermore, the inflow of gas in the wellbore fluid provides valuable information on the various earth formation layers crossed by the wellbore. Thus, gas inflow may be indicative for hitting a hydrocarbon rich prospect or for an emerging hazardous blowout. Gas species which are most common in earth formation layers are methane (CH_4), carbon dioxide (CO_2) and nitrogen (N_2). Also H_2S may be encountered during wellbore drilling.

These gas species may occur either as free-gas bubbles or as gas dissolved-in-liquid.

Until now it has been difficult to detect the presence of earth formation gases during wellbore drilling in a timely and accurate manner.

It is therefore an object of the invention to provide a reliable and accurate system for detecting the presence of formation gas in a stream of drilling fluid flowing through a wellbore during drilling of the wellbore.

In accordance with the invention there is provided a system for detecting the presence of formation gas in a

stream of drilling fluid flowing through a wellbore
during drilling of the wellbore, the system comprising at
least one sensor chamber connectable to a drill string
for drilling the wellbore, each sensor chamber containing
a sensor and a volume of a selected gas and having a
membrane wall which allows passage of formation gas from
the stream of drilling fluid into the sensor chamber, the
sensor being arranged to detect a change of a selected
characteristic of said volume of gas due to passage of
formation gas from the stream of drilling fluid via the
membrane wall into the sensor chamber.

The membrane wall allows gas to pass into the sensor
chamber. By detecting the change of the selected
characteristic due to gas having passed the membrane, it
is achieved that a signal indicative of such gas passage
is timely provided.

Preferably, the membrane wall is both hydrophobic and
oleophobic. Herewith both oil and water are effectively
kept out of the sensing chamber, by virtue of which is
possible to provide a Micro-Electro-Mechanical-Sensor
solid-state sensor ("MEMS sensor") as the sensor. Such
MEMS sensor can be silicon based and/or polymer based.
Various types of MEMS sensors can be used, including a
thermal conductive sensor, a thermo catalytic sensor, and
an electro-chemical sensor, such as a metal-oxide
electro-chemical sensor.

In an advantageous embodiment, the system comprises a
pressure balancing device arranged to maintain the gas
pressure in the sensor chamber substantially equal to the
fluid pressure in the stream of drilling fluid. Due to
the low pressure difference between the gas in the sensor
chamber and the fluid pressure in the well bore, the
membrane wall can have a low break-through pressure which

is advantageous for the response time of the system to changes in concentration of formation gas in the drilling fluid. Moreover, since the gas pressure is balanced with the fluid pressure, the system is suitable for use at any

5   depth.

In a particular advantageous embodiment of the invention, the system comprises a first said sensor chamber and a second said sensor chamber, and wherein the gas supply device includes means for supplying a first

10   said selected gas to the first sensor chamber and means for supplying a second said selected gas to the second sensor chamber. Each of the sensor chambers has its own individual response to the presence of formation gas of a certain type, allowing for down hole compositional

15   analysis of formation gas by combining the sensor signals.

The invention will be described hereinafter in more detail and by way of example with reference to the accompanying drawings in which:

20   Fig. 1 schematically shows a drill string provided with an embodiment of the system of the invention;

Fig. 2 schematically shows a detail of the system of Fig. 1;

Fig. 3 schematically shows an alternative pressure

25   balancing device for the system of Fig. 1; and

Fig. 4 schematically shows an alternative embodiment of the system of the invention.

In the Figures like reference numerals relate to like components.

30   Referring to Fig. 1 there is shown a drill string 1 extending into a wellbore 2 formed in an earth formation 4. The drill string 1 has a drill bit 6 at its lower end, and is provided with a gas detection system 8

suitably arranged in a recess 10 formed in the wall 11 of
the drill string 1 a short distance above the drill
bit 6. Reference sign 12 indicates a stream of drilling
fluid pumped through the drill string 1 to the drill
5   bit 6 where the stream flows via drill bit nozzles 14
into the wellbore 2 and upwardly through the annular
space 16 between the wellbore wall and the drill
string 1.

        As shown in Fig. 2 in more detail, the gas detection
10   system includes a sensor chamber 18 fixedly positioned in
the recess 10 of the drill string wall 11. The sensor
chamber 18 has a membrane wall 20 with a repelling force
for the fluids in the wellbore. The membrane wall 20 is
formed of a stack of a hydrophobic (water repelling)
15   membrane 22 and an oleophobic (oil repelling)
membrane 24. The membranes 22, 24 are diffusive to gas,
i.e. they allow gas to pass from the stream of drilling
fluid 12 into the sensor chamber 18 while preventing
water (membrane 22) and oil (membrane 24) to flow into
20   the sensor chamber 18. A Micro-Electro-Mechanical-Sensor
solid-state sensor 26 ("MEMS sensor") is arranged in the
sensor chamber and suitably connected to a control system
(not shown) at surface. The sensor 26 is a thermal
conductive MEMS pellistor sensor and includes a heat
25   source and a temperature sensor arranged at a selected
distance from the heat source.

        The sensor chamber 18 is filled with a volume of a
selected purge gas. In this example the purge gas is
Helium, however it can also be Neon, Argon or any other
30   suitable reference gas.

        A supply of Helium is provided in storage vessel 28
with is connected to the chamber 18 by a conduit 30 and
control valve 32.

A pressure balancing device 34 is provided to
maintain the gas pressure in the sensor chamber 18
substantially equal to the fluid pressure in the stream
of drilling fluid 12. The pressure balancing device 34 in
5   accordance with the embodiment shown in Fig. 2 comprises
a housing 36 having a liquid chamber 38 and a gas
chamber 40 separated from the liquid chamber 38 by a
flexible wall 41. The liquid chamber 38 is in fluid
communication with the stream of drilling fluid 12 by
10   conduit 42 and the gas chamber 40 is in fluid
communication with the interior of the sensor chamber 18
by conduit 43 and conduit 30. An outlet conduit 44 having
a control valve 45 provides fluid communication between
the sensor chamber 18 and the stream of fluid 12. The
15   flexible wall 40 in the housing 36 is, for example,
formed of an elastomer material. The control valves 32,
45 are controlled by a suitable control system (not
shown).

Fig. 3 schematically shows an alternative pressure
20   balancing device 74. This embodiment differs from the one
described above in that there is no flexible wall
provided in the housing 36 separating the liquid 78 from
the gas 80. The liquid 80 can be supplied to the
housing 36 via an open connection conduit 42, which is
25   optionally provided with a shut-off valve 81. The gas 80
can be the purge gas that is supplied to the interior of
sensor chamber 18 via conduits 43 and 30. An outlet
conduit 44, optionally having a control valve, provides
fluid communication between the sensor chamber 18 and the
30   stream of fluid 12. To ensure proper functioning of this
embodiment, the open connection conduit 42 should be
connected to the housing 36 in a bottom portion of the

housing 36, because the separation of the liquid 78 from
the gas 80 relies on gravity.

    A pressure balancing device generally can also
advantageously be provided in a detection system such as
5   described above having a suitable sensor other than a
MEMS sensor.

    In Fig. 4 is shown an alternative embodiment of the
system of the invention, wherein a first sensor
chamber 50 and an adjacent second sensor chamber 52 are
10   arranged in a recess 10 formed in the drill string
wall 11. The first sensor chamber 50 encloses a first
MEMS sensor 53 and the second sensor chamber 52 encloses
a second MEMS sensor 54. The sensors 53, 54 are connected
to a controller 56 which communicates with a suitable
15   control system (not shown) at surface by control line 58.
A supply of Helium purge gas is provided in storage
vessel 60 with is connected to the first sensor
chamber 50 by a conduit 62 and control valve 63, and a
supply of Argon purge gas is provided in storage
20   vessel 64 with is connected to the second sensor
chamber 52 by a conduit 66 and control valve 67. The
control valves 63, 67 are controlled by controller 56
which in turn is controlled by the control system at
surface. The controller is powered by a battery 68.

25   During normal operation of the embodiment of Figs. 1
and 2 the drill string 1 is rotated in order to further
drill the wellbore 2, whereby the stream of drilling
fluid 12 is circulated down through the drill string 1
and up through the annular space 16 between the wellbore
30   wall and the drill string 1. The sensor chamber is filled
with the selected purge gas Helium. As discussed below,
the purge gas is replenished after each formation gas
measurement. The MEMS sensor continuously transmits a

signal representing the thermal conductivity of the
volume of gas present in the sensor chamber 18. The
signal will be substantially constant as long as no
formation gas enters the sensor chamber 18.

5   When the wellbore 2 penetrates a formation layer
containing gas, such as ethane, carbon dioxide or
nitrogen, some of the gas is entrained in the stream of
drilling fluid 12 flowing in the annular space 16. The
gas can be dissolved in the liquid or can be in the form
10   of gas bubbles if the fluid becomes over saturated with
gas. Also the gas can be in the form of large slugs in
case the wellbore 2 enters a high-pressure gas reservoir.
The partial pressure of each gas component will be higher
in the stream of fluid 12 than in the sensor chamber 18
15   filled with Helium.

Due to the difference in partial pressure of gas in
the stream of drilling fluid 12 and the sensor
chamber 18, gas present in the stream of drilling 12 will
be driven into the sensor chamber 18 through the
20   membranes 22, 24. This applies for every individual gas
species diluted in the stream of fluid 12. Water from the
stream 12 is prevented from entering the sensor
chamber 18 by hydrophobic membrane 22 and oil from the
stream 12 is prevented from entering the sensor
25   chamber 18 by oleophobic membrane 24. Upon entering of
gas in the sensor chamber 18, the thermal conductivity of
the gas environment around the MEMS sensor 26 will
change. As a result the output signal of the sensor 26
will change from a level related to that of the purge gas
30   to a level related to the formation gas having entered
the sensor chamber 18. The changed signal is indicative
of formation gas having entered the sensor chamber 18.
Therefore the gas measurement in application of the

system of the invention is a differential measurement of
a sample gas relative to a reference purge gas. The gas
volume in the sensor chamber 18 is relatively small so
that only small volume of sample gas from the stream of
fluid 12. Consequently the time for analysis is short and
only a small volume of purge gas is needed to clean the
sensor chamber 18 in preparation of a next measurement.

A number of measurements are taken, whereby after
each measurement the sampled gas is removed by opening
control valve 32 thereby purging the sensor chamber 18
with Helium from the storage vessel 28.

The pressure balancing device 34,74 ensures that the
gas pressure in the sensor chamber 18 is substantially
equal to the fluid pressure in the stream of drilling
fluid 12. In this manner it is achieved that the
membranes 22, 24 are not damaged due to high pressure
differences across the membranes 22, 24. Thus, by virtue
of the pressure balancing device 34,74 the system can be
used in deep well bores at depths of for instance 1 km or
more, or 3 km or more, allowing the system to be as close
as possible to the lower end of the drill string. Having
the system at as close to the lower end of the drill
string contributes to the early detection of formation
gas originating deep in the well bore.

Moreover, the pressure balancing device 34,74 allows
for provision of a relatively thin membrane wall with a
relatively large surface area, which is advantageous for
minimizing any time delay between the appearance of
formation gas in the stream of drilling fluid and the
earliest detection of it.

The described embodiment of the pressure balancing
device 34 has a liquid chamber 38 communicating with the
stream of fluid in the wellbore annulus 16, and a gas

chamber 40 communicating with the gas filled sensor
chamber 18. By this arrangement pressure communication
exists between the gas filled sensor chamber 18 and the
fluid filled wellbore annulus 16. At the same time the

5   flexible wall 41 separates the stream 12 from the gas in
the sensor chamber 18. Thus, the pressure balancing
device 34 separates the fluids in the wellbore from the
gas inside the chamber 18.

The described alternative embodiment of the pressure

10   balancing device 74 has a liquid 78 communicating with
the stream of fluid in the wellbore annulus 16, and a
gas 80 communicating with the gas filled sensor
chamber 18. By this arrangement pressure communication
exists between the gas filled sensor chamber 18 and the

15   fluid filled wellbore annulus 16. Since there is no
flexible wall separating the stream 12 from the gas in
the sensor chamber 18, this embodiment is preferred for
ensuring that no pressure difference can exist between
the liquid and the gas as a result of possible mechanical

20   support that could be provided by a flexible wall.
However, in this alternative embodiment, there is a risk
that fluid enters the sensor chamber.

In order to compensate for the relatively large gas
compression during the first approximately 500 m depth

25   while lowering the system in a wellbore, the purge gas
present in the housing 36 can optionally be pre-
pressurized with a closed shut-off valve 81. When
reaching the approximately 500 m depth the shut-off valve
can be opened to achieve the open connection to the

30   wellbore. Herewith the volume required for the gas 80 in
the housing 36 can be reduced.

Capillary pressures in the membranes 22, 24 lead to a
relatively small pressure difference across the

membranes 22, 24. By selecting membranes 22, 24 with very
small pores, such pressure difference may range from
2-14 bars. In order to purge the sensor chamber 18 the
Helium gas pressure in storage vessel 28 should be higher
than the maximal anticipated wellbore pressure.

As a measurement method it may be selected to utilize
signal amplitudes whereby, following an initial
disturbance, the signal becomes stable after a relative
long period of time, i.e. around 80 minutes for each
measurement. A more preferred method involves measurement
of the slope of the output signal as it changes in time
due to diffusion of formation gas into the sensor
chamber 18. This is a fast measurement of about
15-20 seconds turnaround time. Each measurement involves
alternating purge gas inflow and formation gas inflow,
with 15 seconds interval. In order to improve the
accuracy statistical averaging can be carried out over
large number of data samples. The slope of the output
signal is proportional to the partial dissolved gas
concentration. Furthermore, free gas in the stream 12
shows a significantly different slope than gas dissolved
in the stream 12, so that such difference can be used for
recognition of the gas phase, i.e. either gas-in-liquid
or as free gas in the drilling fluid return stream from
the drill bit 6.

Normal operation of the embodiment of Fig. 4 is
substantially similar to normal operation of the
embodiment of Figs. 1, 2 and 3. The main difference is
that two different purge gases, Helium and Argon, are
used for the respective sensor chambers 50, 52 instead of
one purge gas. Initially sensor chamber 50 is filled with
Helium and sensor chamber 52 is filled with Argon. When
formation gases methane, carbon dioxide and nitrogen

enter the sensor chambers 50, 52, the thermal
conductivity of the gas volume in sensor chamber 50
changes differently than the thermal conductivity of the
gas volume in sensor chamber 52. Thus the sensor signal
5   of sensor 53 changes differently than the sensor signal
of sensor 54. Furthermore, the signal changes depend on
the concentrations of the respective gas components
methane, carbon dioxide and nitrogen. By calibrating the
signal from sensor chamber 50 for the gas components
10   methane, carbon dioxide and nitrogen, a first equation is
obtained from the measurement at a selected temperature
of the sensor internals. A second equation follows by
considering that the sum of all concentration of three
gas components CO_2, N_2 and CH_4 add up to one. A third
15   equation is obtained by calibrating the signal from
sensor chamber 52 for the gas components methane, carbon
dioxide and nitrogen. By solving these equations,
compositional information can be extracted.

Each sensor 53, 54 has its own electronic settings
20   and gain such that signal levels are optimized for read-
out and for solving the set of 3 equations and 3
unknowns. Possibly the 3-gas species detection problem
can be reduced to a 1-gas species detection problem by
making use of prior knowledge on the well. For instance
25   by assuming that in a certain well the Methane
concentration in natural gas is the only variable.

It is also possible to use an expected formation gas,
such as N_2, CH_4, or H_2S in one of the sensor chambers. A
chamber filled with that type of gas does not display a
30   change in the selected characteristic of the gas detected
by the sensor. If a second sensor chamber does display a
change in the selected characteristic at the same time,

this is a direct and fast indication that this type of
formation gas is present in the stream of drilling fluid.